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RESEARCH MEMORANDUM

A BRIEF HYDRODYNAMIC INVESTIGATION OF A NAVY SEAPLANE DESIGN EQUIPPED WITH A HYDRO-SKI

By Lloyd J. Fisher and Edward L. Hoffman

Langley Aeronautical Laboratory
Langley Field, Va.

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RESEARCH MEMORANDUM

A BRIEF HYDRODYNAMIC INVESTIGATION OF A NAVY SEAPLANE DESIGN EQUIPPED WITH A HYDRO-SKI

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SUMMARY

A limited investigation of a 1/24-scale dynamically similar model of a Navy Bureau of Aeronautics design was conducted in Langley tank no. 2 to determine the calm-water take-off and the rough-water landing characteristics of the design with particular regard to the take-off resistance and the landing accelerations. During the take-off tests, resistance, trim, and rise were measured and photographs were taken to study spray. During the landing tests, motion-picture records and normal-acceleration records were obtained.

A ratio of gross load to maximum resistance of 3.2 was obtained with a 30° dead-rise hydro-ski installation. The maximum normal accelerations obtained with a 30° dead-rise hydro-ski installation were of the order of 8g to 10g in waves 8 feet high (full scale). A yawing instability that occurred just prior to hydro-ski emergence was improved by adding an afterbody extension, but adding the extension reduced the ratio of gross load to maximum resistance to 2.9.

INTRODUCTION

The subject aircraft is a Navy Bureau of Aeronautics design study of a high-performance jet-propelled seaplane incorporating a stepless hull with retractable hydro-ski alighting gear. The hydro-ski gear is of interest as a possible answer to the aerodynamic drag penalties and hydrodynamic load penalties usually associated with seaplanes. The design has a gross take-off weight Δ_o of 160,000 pounds, a wing loading Δ_o/S of 100 pounds per square foot, a static thrust loading Δ_o/T of 3.1, and a hydro-ski gross-load coefficient C_{Δ_o} of 16.5.

[redacted]

A limited investigation was conducted to determine the calm-water take-off and the rough-water landing characteristics of the design. Various hydro-ski configurations were investigated in an effort to obtain the minimum take-off resistance and low landing accelerations. Only the data obtained from one ski configuration are presented in this report. This configuration is presented as a reasonable compromise between the requirements for resistance, landing loads, and stability. The investigation was conducted in Langley tank no. 2 using the main towing carriage.

SYMBOLS

b_s	beam of hydro-ski, ft
C_{Δ_o}	hydro-ski gross-load coefficient, $\frac{\Delta_o}{wb_s^3}$
$\bar{c}$	mean aerodynamic chord, ft
D	air drag, lb
g	acceleration due to gravity (32.2), ft/sec/sec
i_s	angle of incidence of hydro-ski with respect to hull W.L. 0 (fig. 1), deg
L.W.L.	load water line
n	normal acceleration, g units
R	water resistance, lb
r	rise of center of gravity, ft
S	wing area, sq ft
T	static thrust, lb
V	speed, ft/sec
W.L.	construction water line

w	specific weight of water; 64 lb/cu ft arbitrarily used for these tests
Δ	load on the water, lb
Δ_0	initial load on the water, gross load, lb
δ_e	elevator deflection, deg
δ_f	flap deflection, deg
τ	trim measured as angle between hull W.L. 0 and undisturbed water surface, deg

MODEL DESCRIPTION

Hull and hydro-ski lines and general arrangement drawings of the seaplane design were furnished by the Bureau of Aeronautics. From these drawings a 1/24-scale dynamically similar model, designated Langley tank model 280, was designed and constructed at the Langley Aeronautical Laboratory for use in the tank investigation. A general arrangement drawing of the full-scale airplane is given in figure 1. Photographs of model 280 are given in figure 2. Drawings of the 30° dead-rise hull and hydro-ski are given in figures 3 and 4. Pertinent dimensions of the full-scale seaplane and the tank model are listed in table I. Offsets for the hull and hydro-ski are presented in tables II and III, respectively.

The model was of balsa-wood construction with hardwood and aluminum reinforcements at areas of concentrated stress. Internal ballast was used to obtain scale weight and an assumed pitching moment of inertia. The elevators were adjustable to fixed positions through a ±30° range. The afterbody extension shown in figure 3 could be easily installed on or removed from the model.

The hydro-ski was attached to the model by a rigid strut that could be adjusted to vary the strut length and the angle of incidence of the ski. A second bracing strut was added near the bow of the ski for rough-water landing tests (fig. 2). The location of the pivot point about which the ski incidence was changed is shown in figure 4. Longitudinal and vertical locations of the ski as used herein are given with respect to the trailing edge and keel of the ski when at a 0° angle of incidence. Since the pivot point was fixed, the vertical and longitudinal location of the ski trailing edge changed slightly as the angle of incidence was varied.

APPARATUS AND PROCEDURE

Take-Off Tests

The resistance tests were conducted on the tank no. 2 small-model towing gear shown in figure 5. The model was towed in calm water at constant speeds with fixed elevators and was free to trim about the center of gravity and to rise. The resistance, trim, and rise were measured and still photographs were taken at various conditions to study spray. The elevator deflections and ski positions were varied to determine the minimum resistance and stable take-off positions. A tare correction for the air drag of the towing staff was made to the resistance data.

Power was not simulated on the model but the moment due to engine thrust was simulated with a balance weight. Corrections to the measured resistance for the lift due to thrust were also made. The corrections were based on the assumption that the ratio of the load on the water to the resistance remained constant with small changes in the load on the water as follows:

$$\Delta = \Delta_0 - \text{Aerodynamic lift}$$

$$\Delta_{corrected} = \Delta - \text{Lift component of thrust}$$

$$R_{corrected} = \frac{R}{\Delta} \Delta_{corrected}$$

Stability trim limits and center-of-gravity limits were not obtained, but some take-off runs at a constant acceleration of 2 feet per second per second were made to determine whether stable take-off runs could be made, to study the spray characteristics, and to get a comparison between the trims and ski emergence speeds for accelerated runs and constant-speed runs. The results of the accelerated runs were obtained from trim readings, visual observations, and by motion-picture records.

Landing Tests

Free-body landings were made perpendicular to waves by launching the model from the towing carriage using the gear shown in figure 6. The model was attached to the gear at a trim of 12° with the control surfaces set to hold this attitude in flight. At a predetermined time a securing hook was released and the air drag caused the model to drop from the gear. The preset control surfaces kept the model at approximately the desired trim during the free glide from release to landing. The landings were made at a speed of 113 knots (full scale).

Waves were generated by an oscillating plate hinged at the bottom of the tank. The waves were 4 inches high (8 feet high, full scale) with length-height ratios of 30, 40, and 50. Motion-picture records were taken of the landings to study the stability and spray characteristics of the model.

A Statham strain-gage-type accelerometer was installed directly below the center of gravity of the model to measure normal accelerations. The natural frequency of the accelerometer and the recording galvanometer was 150 cycles per second and both were damped to about 65 percent of critical. A trailing wire from the carriage to the model was employed to complete the circuit between the accelerometer and the recording galvanometer. Vibration tests of the model showed that the wing had a natural frequency of about 23 cycles per second and the fuselage had a natural frequency of about 85 cycles per second. These frequencies appeared on some of the accelerometer records. The data presented herein were obtained by fairing through the vibrations appearing on the accelerometer records.

RESULTS AND DISCUSSION

Resistance

The hydrodynamic resistance of the model with the afterbody extension on and the hydro-ski located as shown in figure 1 but at -1° incidence is given in figure 7(a). The data were obtained with an elevator setting of -20°. Varying the elevator setting did not appreciably change the low speed or hump resistance but changed the resistance at speeds above hump speed. The resistance of the model was reduced some from that shown in figure 7(a) by using a hydro-ski of greater size or different shape, by removal of the afterbody extension, or by moving the ski forward; but the above-mentioned configuration was a reasonable compromise between the requirements for resistance, landing loads, and stability. A ratio of gross load to maximum resistance of 2.9 was obtained in this case. The resistance of the model without the afterbody extension is given in figure 7(b). Without the afterbody extension the hydro-ski emergence speed was lower and a ratio of gross load to maximum resistance of 3.2 was obtained.

Take-Off Stability

With the hydro-ski located as shown in figure 1, stable accelerated take-off runs were obtained. A comparison of the trim tracks obtained from accelerated runs and constant-speed runs with a ski incidence of -1° showed only minor variations in trim. There was no noticeable change in ski emergence speeds.

It was noted in both the constant-speed resistance tests and the accelerated runs of the take-off tests that the model was unstable in yaw just before the ski emerged. The instability (which was apparently caused by flow around the aft portion of the hull) was much less noticeable in accelerated runs than in constant-speed runs but was still undesirable. The afterbody extension shown in figure 3 greatly improved the directional stability. The resistance was somewhat higher with the afterbody extension.

Landing Stability

The landing behavior of the model in rough water depended primarily on how the model contacted the waves but was also affected by the angle of incidence and the vertical location of the hydro-ski. In general, the model gave two different behaviors, depending on the part of the model that made initial contact with the waves. If the hydro-ski made the initial contact with the water, the ski sliced through the wave and the model skipped from wave to wave with little change in trim or rise. This is the type of rough-water landing that is considered ideal with ski-equipped seaplanes and was obtained on this model at all vertical locations and angles of incidence of the ski. The model tended to bounce less, however, at the lower angles of ski incidence.

The other type of rough-water behavior occurred when the stern of the hull made the initial contact with the water. The stern contact caused the model to pitch down so that the ski entered the next wave at a very low positive angle or sometimes at a negative angle of trim. The model then trimmed up rapidly, skipped high off the water and fell heavily into a succeeding wave. It was found that this rapid trimming up and high skipping could be prevented by installing the ski very close to the hull; however, the vertical location shown in figure 1 was necessary for satisfactory take-off resistance and stability. Using the vertical location of figure 1 and reducing the ski incidence angle to -2° also reduced the trimming up and high skipping when the tail made the initial contact; however, no further reduction in incidence was tested.

Spray

The spray characteristics for calm-water take-off runs were relatively good as can be seen in figure 8. At no time in the calm-water take-off tests for either constant-speed or accelerated runs was there any spray in the intake openings. Just before and for a short while after the ski emerged, there was some spray on the flaps. The most objectionable spray was on the horizontal tail surface and came from the ski after the ski emerged.

The flaps were wetted heavily in rough-water landings. The elevators were also wetted at times in rough-water landings and occasionally water entered the intake ducts when the nose of the model contacted a wave.

Landing Acceleration

Maximum normal accelerations obtained from landings in waves of various length-height ratios and with various angles of ski incidence are presented in table IV. Since the maximum normal accelerations obtained both with and without the afterbody extension were practically the same and since more complete data were obtained with the afterbody extension, the accelerations listed in table IV are for this configuration. An accelerometer record obtained from a landing in waves having a length-height ratio of 30 is shown in figure 9. The second impact from the record of figure 9 is plotted in figure 10(a). The solid line shows how the accelerometer record was faired. In this particular impact the initial contact with the water was made by the ski on the approaching flank of a wave. Initial contact produced the first high peak of the record and induced some fuselage vibration. Then as the ski continued through the wave the hull of the model contacted the wave and produced the second high peak of the record.

Figure 10(b) presents as a dashed line the acceleration record of the initial contact of a landing in waves having a length-height ratio of 40. In this case the ski and afterbody contacted the approaching flank of a wave. The solid line shows how the record was faired. In this instance the peak acceleration was not reduced by fairing since fuselage vibrations were not present and since it was assumed that the amplitude of the wing vibration did not materially affect the peak.

From table IV it can be seen that the maximum normal accelerations obtained in waves of various length-height ratios were of the order of 8g to 10g and that the hydro-ski incidence had little effect on the maximum accelerations.

CONCLUSIONS

The following conclusions were drawn from model tests of a Navy Bureau of Aeronautics seaplane design:

1. A ratio of gross load to maximum resistance of 3.2 was obtained with a 30° dead-rise hydro-ski installation.

2. The maximum normal accelerations obtained with a 30° dead-rise hydro-ski installation were of the order of 8g to 10g in waves 8 feet high.

3. A yawing instability that occurred just prior to hydro-ski emergence was made less objectionable by adding an afterbody extension, but adding the extension reduced the ratio of gross load to maximum resistance to 2.9.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 20, 1953.

TABLE I.- PERTINENT DIMENSIONS OF NAVY BUREAU OF AERONAUTICS SEAPLANE DESIGN AND LANGLEY TANK MODEL 280

	Full size	Model
General:		
Design gross load:		
Take off, lb	160,000	11.57
Landing, lb	115,000	8.32
Pitching moment of inertia, slug-ft^2	1,750,000	0.22
Static thrust, lb	51,000	3.69
Static thrust moment, lb-ft	-127,000	-0.38
Over-all length, ft	103	4.29
Over-all height, ft	36.25	1.51
Center-of-gravity location:		
Percent mean aerodynamic chord	26	26
Height above keel, ft	10.5	0.44
Hull:		
Length, ft	91.78	3.83
Maximum beam, ft	10.33	0.43
Height, ft	13	0.54
Angle of dead rise, deg	30	30
Length-beam ratio	8.88	8.88
Wing:		
Area, sq ft	1600	2.78
Span, ft	98	4.08
Sweepback of 25-percent-chord line, deg	35	35
NACA airfoil section	64A410	64A410
Incidence, deg	3	3
Mean aerodynamic chord, ft	17.33	0.72
Root chord, ft	23.33	0.97
Tip chord, ft	9.34	0.39
Aspect ratio	6	6
Flaps:		
Take-off position, deg	20	20
Landing position, deg	50	50
Horizontal tail:		
Total area, sq ft	384	0.67
Span, ft	41.5	1.73
Vertical tail:		
Total area, sq ft	240	0.42

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TABLE I.- PERTINENT DIMENSIONS OF NAVY BUREAU OF AERONAUTICS

SEAPLANE DESIGN AND LANGLEY TANK MODEL 280 - Concluded

	Full size	Model
Hydro-ski:		
Length, ft	21.28	0.89
Beam, ft	5.32	0.22
Area, sq ft	100	0.17
Length-beam ratio	4	4
Gross loading, lb/sq ft	1600	66.7
Gross-load coefficient	16.5	16.5
Tip floats:		
Length, ft	27	1.13
Beam, ft	3.67	0.15
Height, ft	5	0.21

TABLE II.- HULL OFFSETS FOR LANGLEY TANK MODEL 280

[All dimensions are in inches; angle of chine flare, 0° from hull station 2.30 to station 33.35]

Hull station	Height above hull water line 0				Half-breadth											
	Keel	Chine	Hull at center line	Tangent point	Chine	Tangent point	Hull water line									
							2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
0	4.52		4.52													
.58	3.40		5.06							0.12	0.59	0.57	0.22			
1.15	2.77		5.34	2.77					0.18	.75	.99	.87	.59			
2.30	1.88	2.92	5.73	2.50	1.43	0.54			1.44	1.39	1.30	1.14	.95	0.55		
4.60	.90	2.31	6.16	2.00	1.91	1.13			1.83	1.76	1.64	1.48	1.30	1.03	0.49	
6.90	.48	1.89	6.39	1.61	2.21	1.45	2.19	2.16	2.07	2.01	1.89	1.72	1.53	1.24	.81	
9.20	.30	1.61	6.52	1.36	2.40	1.60	2.37	2.32	2.23	2.15	2.02	1.84	1.67	1.39	.98	0.13
13.80	.08	1.30	6.63	1.11	2.57	1.79	2.52	2.46	2.37	2.29	2.17	2.02	1.84	1.57	1.20	.58
18.40	.00	1.15	6.63	1.03	2.46	1.78	2.37	2.33	2.26	2.18	2.08	1.94	1.76	1.51	1.15	.56
23.00	.00	1.15	6.63	1.03	2.35	1.78	2.31	2.26	2.19	2.12	2.03	1.89	1.72	1.47	1.13	.54
27.60	.22	1.27	6.63	1.18	2.23	1.73	2.21	2.18	2.13	2.06	1.96	1.84	1.68	1.44	1.10	.53
29.90	.35	1.39	6.63	1.33	2.15	1.69	2.14	2.12	2.07	2.01	1.92	1.79	1.63	1.40	1.06	.49
33.35	.70	1.63	6.63	1.57	2.00	1.51	1.99	1.94	1.91	1.85	1.77	1.65	1.52	1.30	.98	.41
36.80	1.03	1.81	6.63	1.76	1.76	1.26	1.76	1.72	1.67	1.62	1.55	1.46	1.32	1.14	.84	.31
39.10	1.27	1.89	6.63	1.86	1.59	1.03	1.59	1.57	1.51	1.46	1.38	1.29	1.18	1.02	.75	.26
43.70	1.72	2.01	6.63	1.95	.88	.37	.88	.87	.84	.82	.76	.71	.64	.51	.45	.10
45.89	1.94	1.94	6.63													

TABLE III.- HYDRO-SKI OFFSETS FOR LANGLEY TANK MODEL 280

[All dimensions are in inches; angle of deadrise, 30°; angle of chine flare, 0°; chine strip extends from hydro-ski station 2.16 to 9.10; angle of chine strip, 45°]

Hydro-ski station	Height above hydro-ski water line 0									Half-breadth chine
	Keel	Chine	Hydro-ski at center line	Chine strip	Buttock lines					
					0.25	0.50	0.75	1.00	1.25	
0	0.66	0.66	0.66							
.50	.30	.64	.78		0.44 .78	0.58 .76	0.64 .72			0.84
1.00	.12	.63	.87		.27 .87	.42 .86	.56 .80	0.63 .73		1.13
1.50	.04	.62	.92		.19 .92	.34 .91	.48 .87	.59 .80	0.62 .68	1.27
2.50	.00	.59	.98	0.35	.14 .96	.29 .94	.43 .90	.55 .83	.59 .68	1.32
3.50	.00	.57	1.00	.25	.14 .99	.29 .97	.43 .92	.53 .86	.57 .70	1.32
5.00	.00	.53	.96	.25	.14 .95	.29 .94	.43 .90	.52 .81	.53 .64	1.32
7.60	.00	.46	.80	.25	.14 .80	.29 .80	.42 .75	.46 .68	.46 .54	1.32
8.40	.00	.44	.74	.30	.14 .73	.29 .72	.41 .68	.44 .61	.44 .48	1.28
9.00	.00	.42	.68	.39	.14 .67	.29 .66	.40 .62	.42 .54		1.19
10.65	.00	.38	.50		.14 .50	.29 .46	.38 .40			.75

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TABLE IV.- NORMAL ACCELERATIONS FROM FREE-BODY LANDINGS OF LANGLEY TANK MODEL 280

[Hydro-ski located at $0.45\bar{c}$ and 0.8b below the hull keel; Δ_o = 115,000 lb; $\delta_f = 50^\circ$; wave height, 8 ft; static accelerometer reading, 1g; afterbody extension attached; all values are full scale]

Run	Maximum normal acceleration, g, for - Initial impact	Maximum normal acceleration, g, for - Maximum impact	Impact for maximum acceleration
Wave length-height ratio, 50; ski incidence, 2°			
1	6.1	6.1	1
2	5.8	9.8	2
3	7.5	7.5	1
4	5.7	5.7	1
5	6.4	6.4	1
Wave length-height ratio, 40; ski incidence, 2°			
1	7.1	7.1	1
2	5.6	6.0	2
3	6.7	6.7	1
4	6.8	6.8	1
5	8.0	8.0	1
Wave length-height ratio, 30; ski incidence, 2°			
1	6.3	6.7	2
2	6.9	6.9	1
3	7.7	9.1	2
4	7.5	7.5	1
5	4.6	5.8	2
6	6.1	6.1	1
Wave length-height ratio, 30; ski incidence, 0°			
1	6.4	6.4	1
2	4.9	6.6	2
3	6.2	6.2	1
4	8.9	8.9	1
5	7.2	7.2	1
Wave length-height ratio, 30; ski incidence, -2°			
1	6.0	7.4	2
2	5.1	5.1	1
3	7.5	7.5	1
4	5.2	7.5	2
5	5.7	8.3	2
6	6.0	6.8	2
7	6.4	7.0	2
8	3.1	7.2	2
9	6.3	6.3	1
10	8.0	8.0	1

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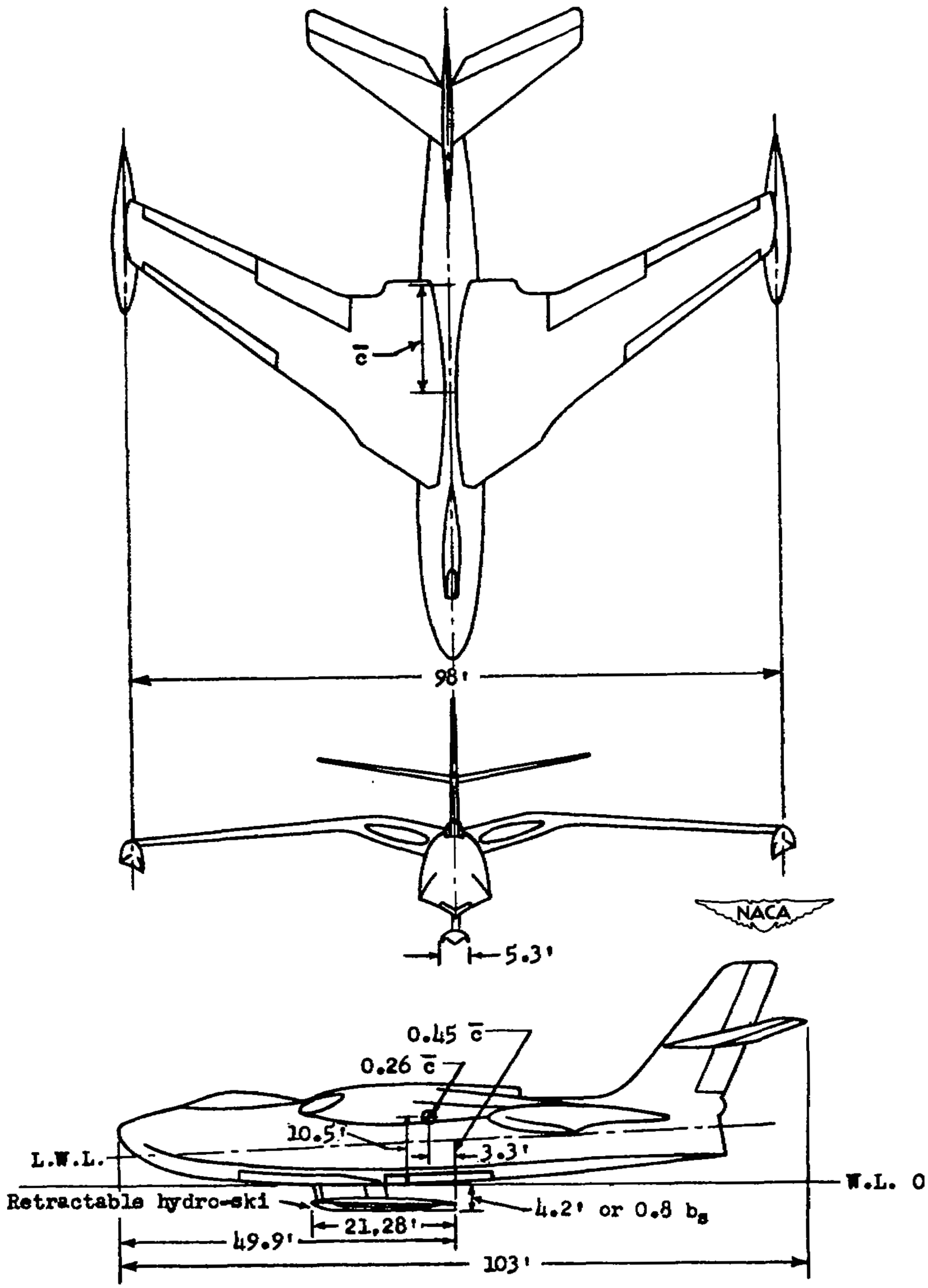
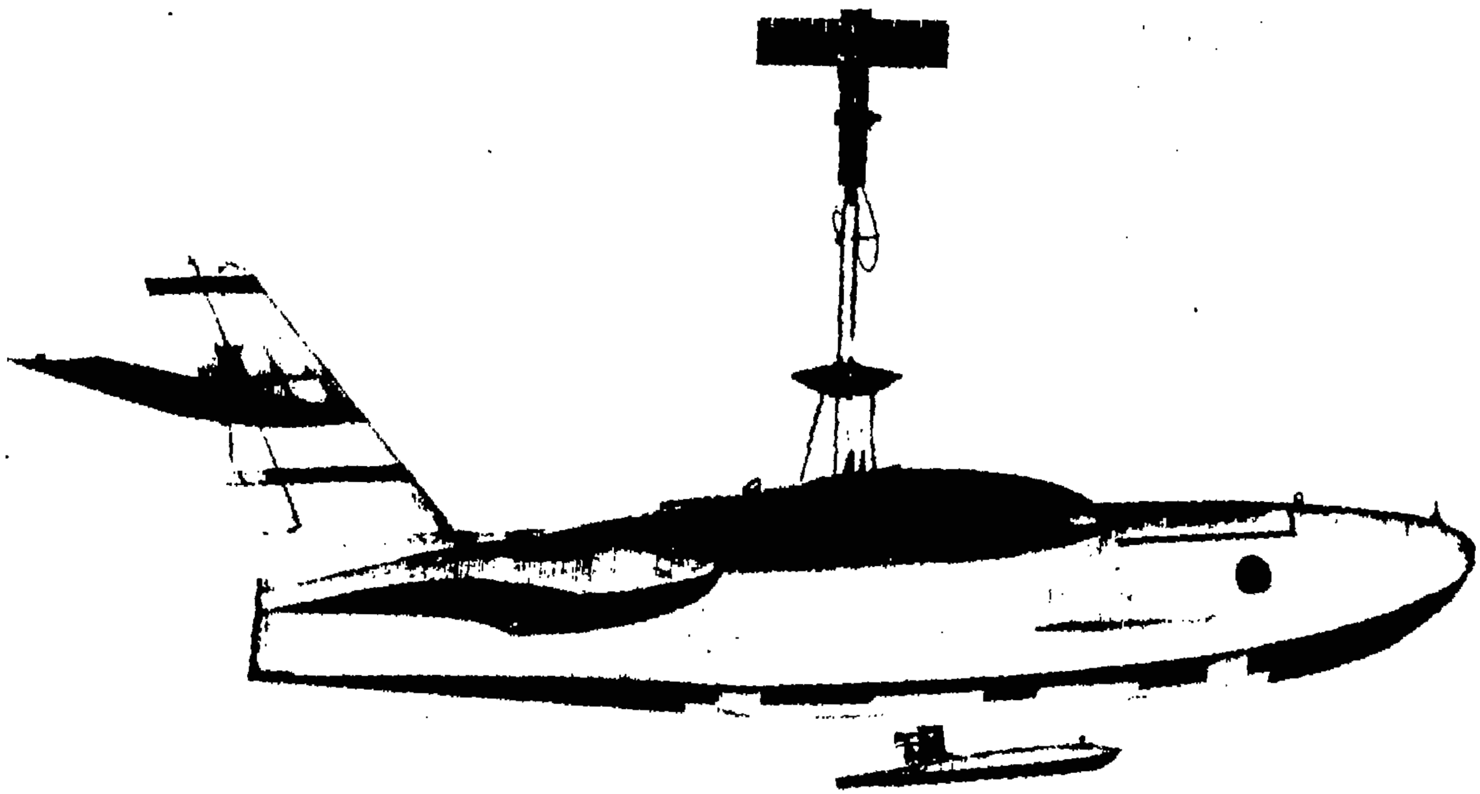


Figure 1.- Three-view drawing of full-scale seaplane.

[redacted]



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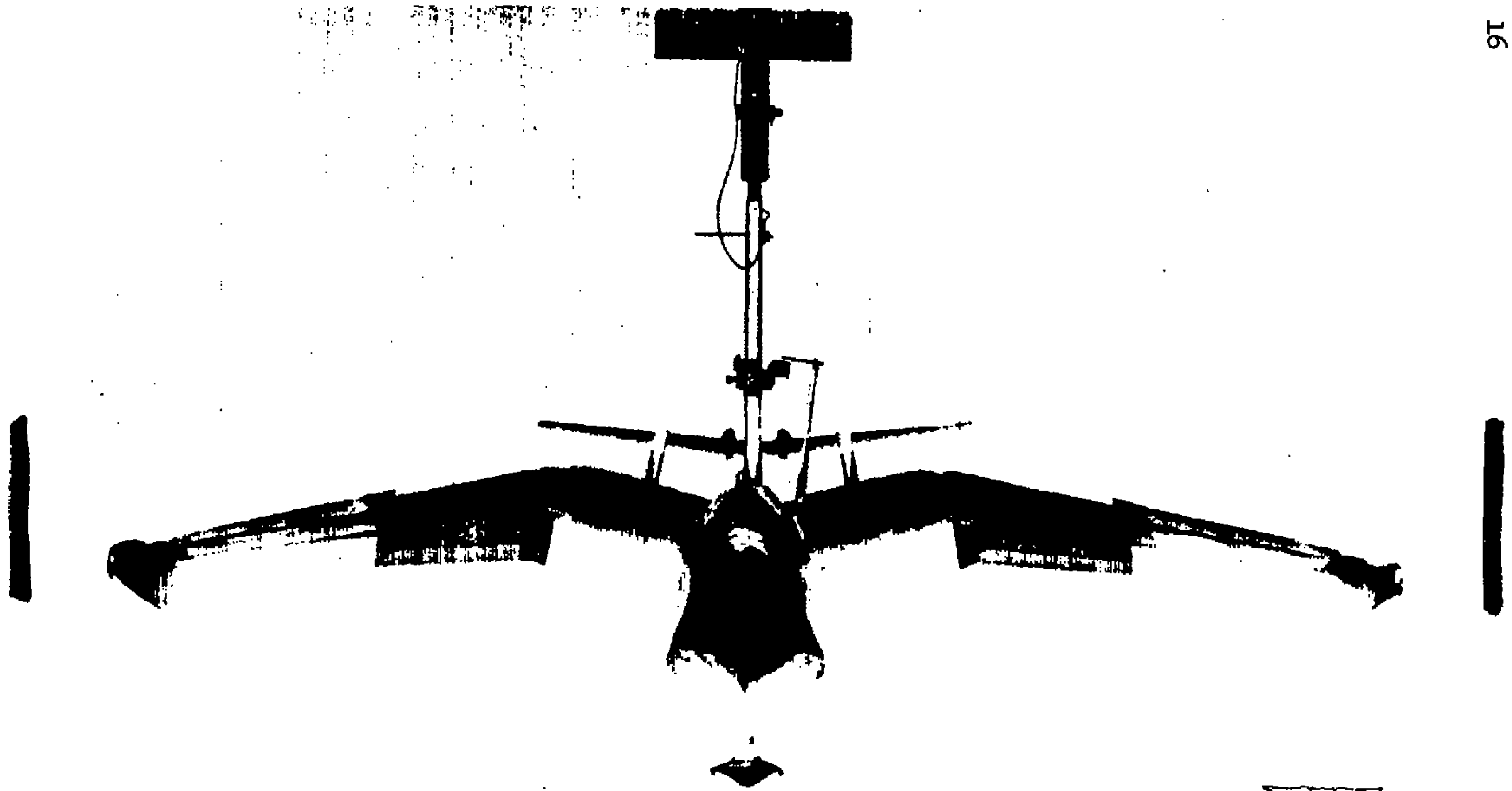
(a) Side view.

Figure 2.- Langley tank model 280.



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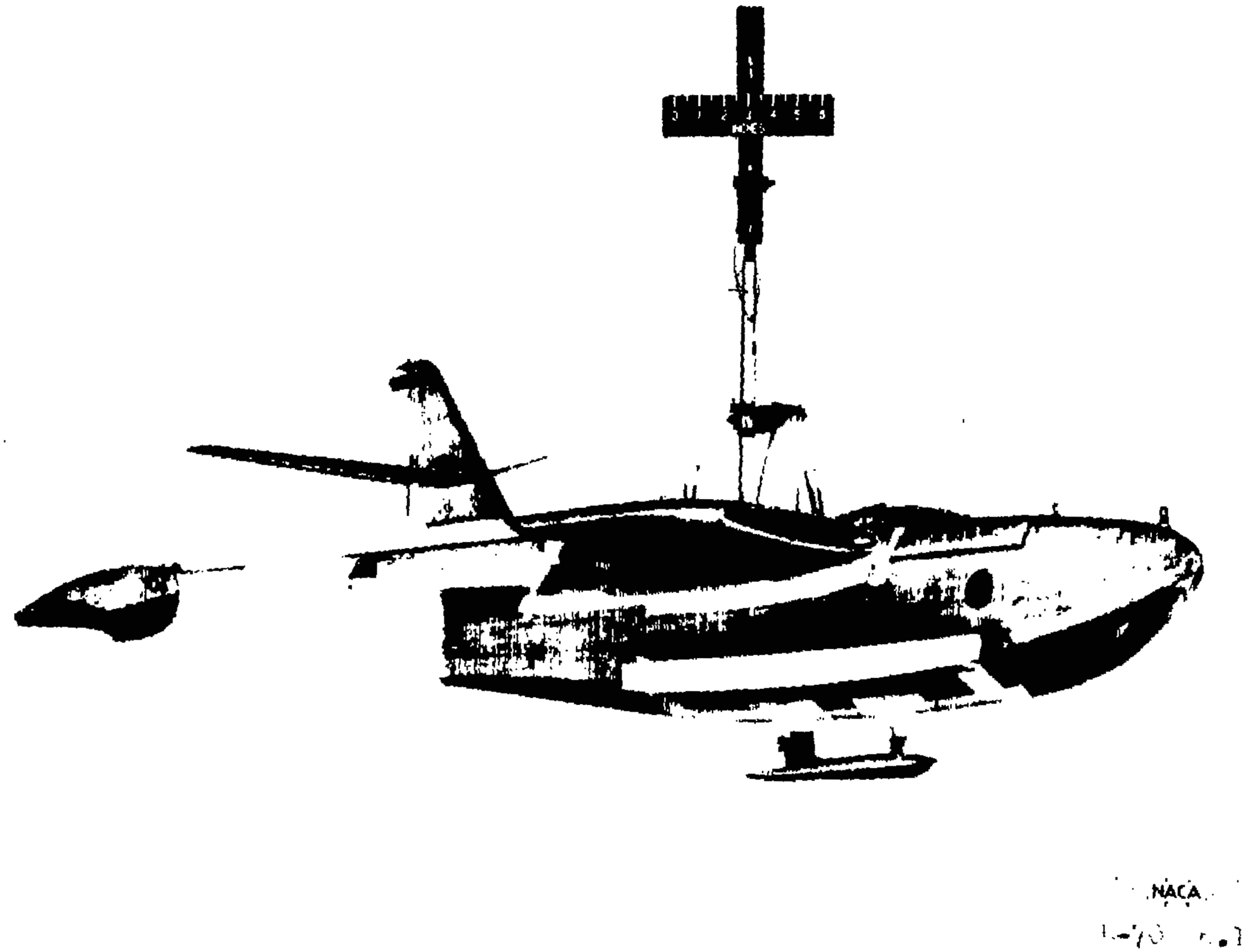
(b) Front view.

Figure 2.- Continued.



(c) Three-quarter front view.

Figure 2.- Concluded.

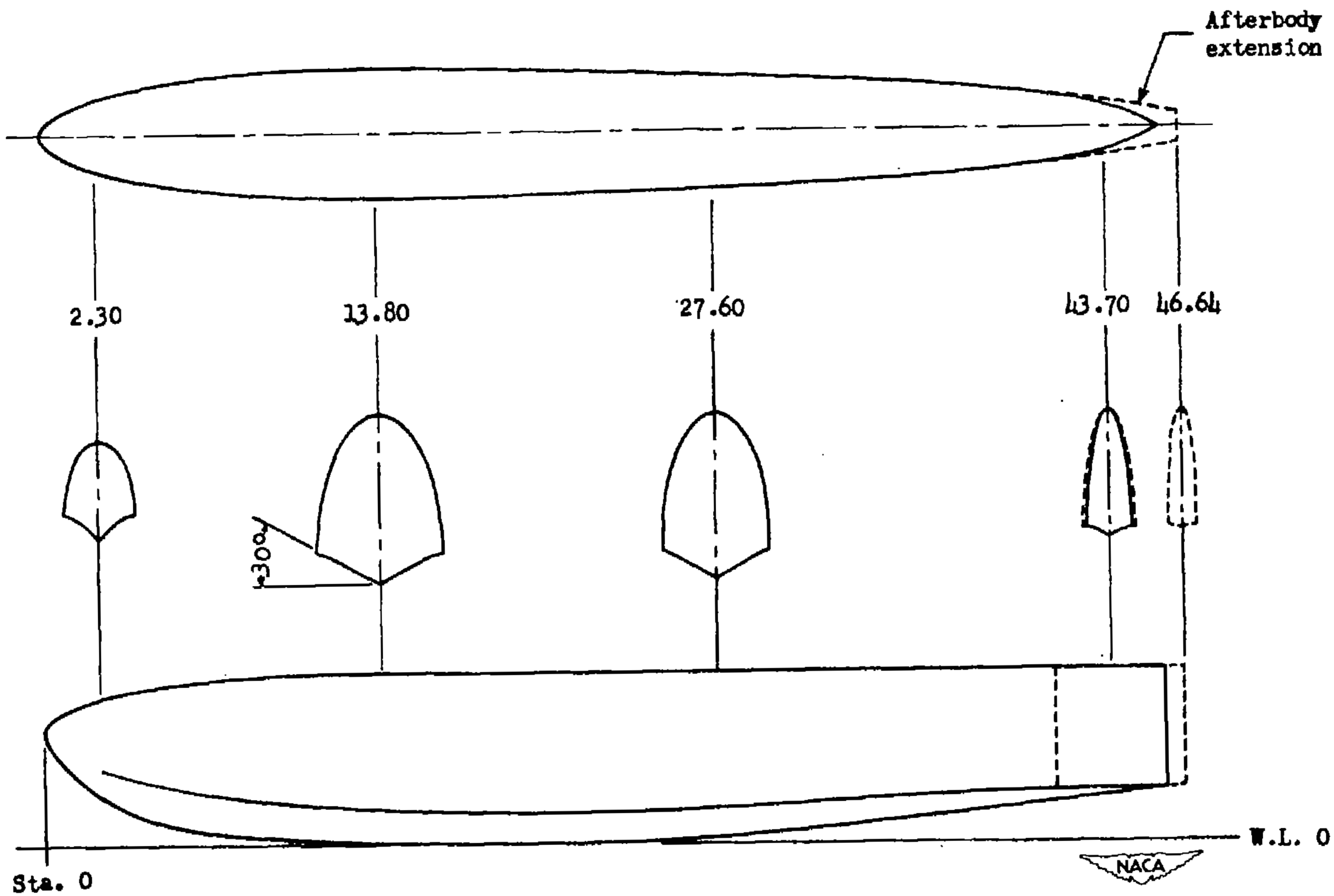


Figure 3.- Lines of hull and afterbody extension of Langley tank model 280.

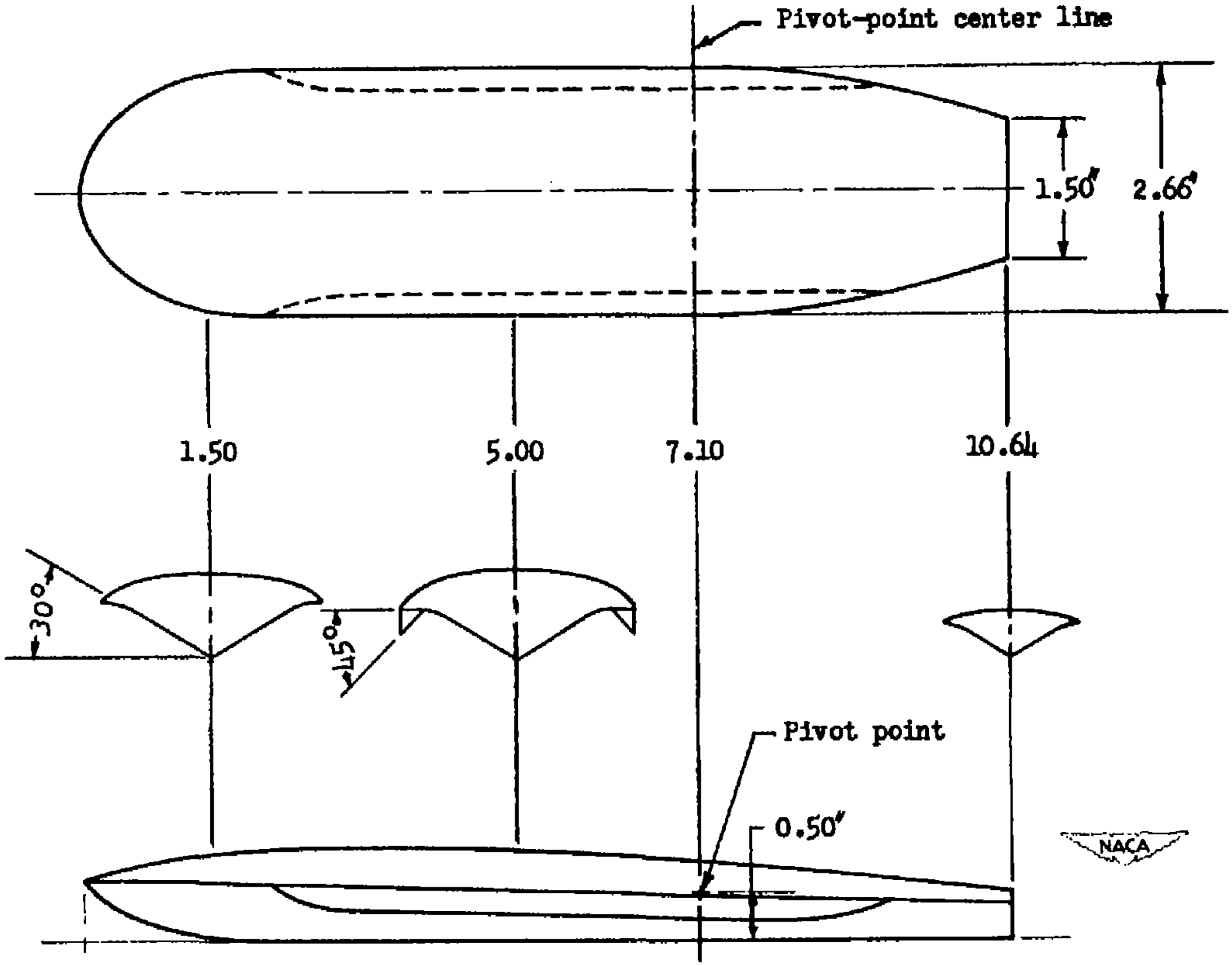


Figure 4.- Lines of hydro-ski of Langley tank model 280.

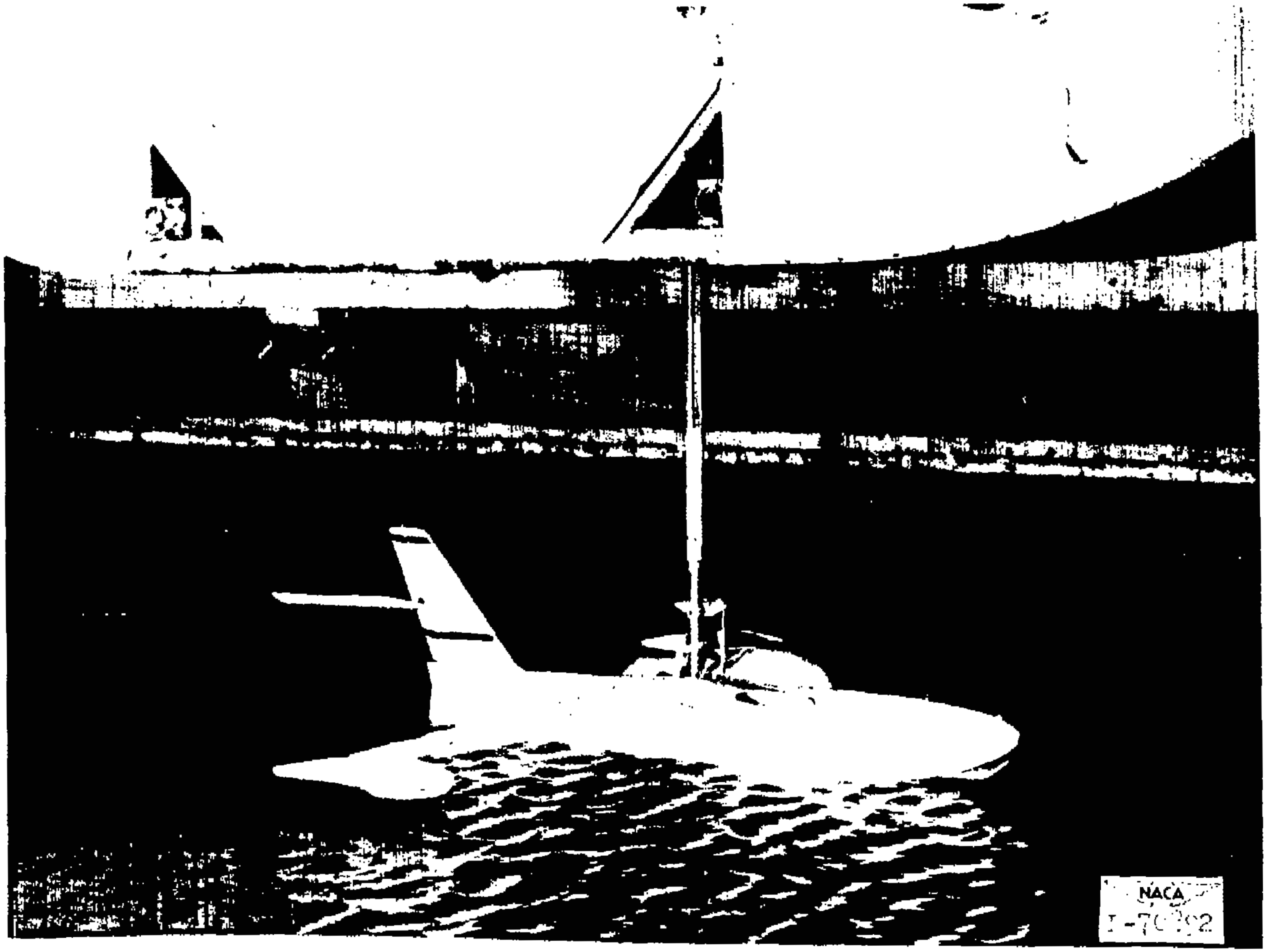


Figure 5.- Setup of model on small-model towing gear.

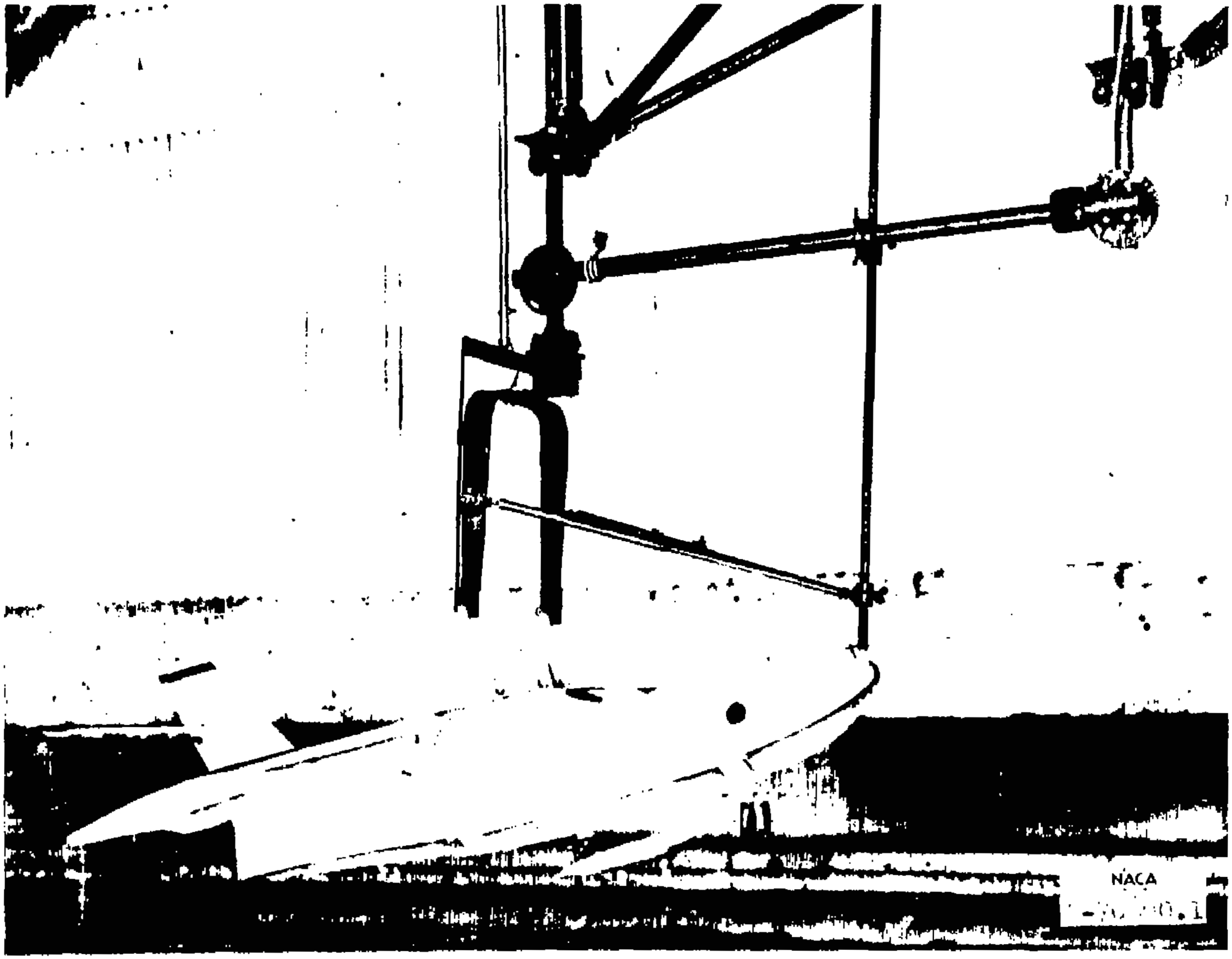
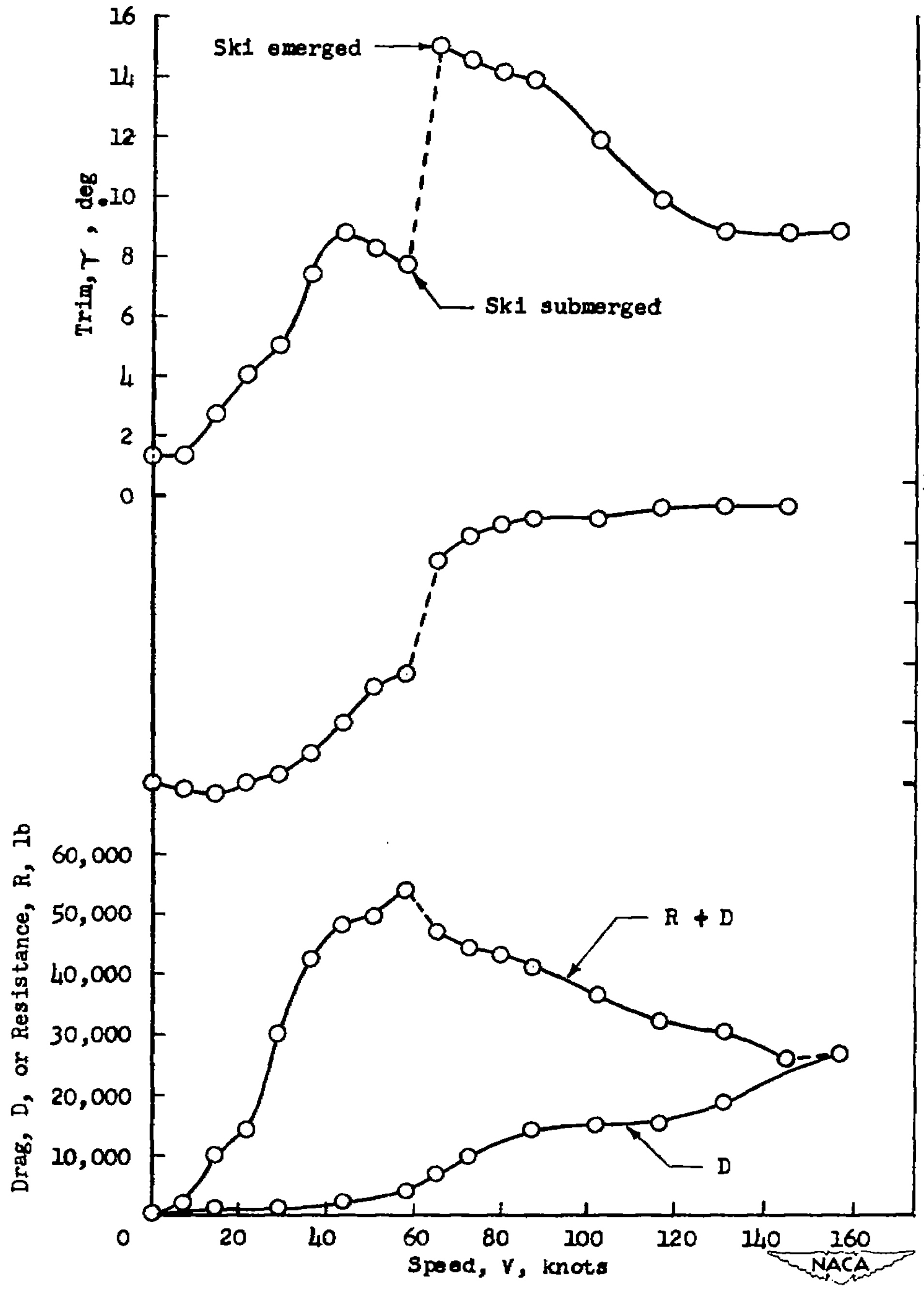


Figure 6.- Setup of model on free-model launching gear.



(a) Afterbody extension attached.

Figure 7.- Resistance, trim, and rise plots for hydro-ski located at $0.45\bar{c}$ and $0.8b_s$ below the hull keel. Δ_o, 160,000 pounds; δ_f, 20°; δ_e, -20°; i_s, -1°; all values are full scale.

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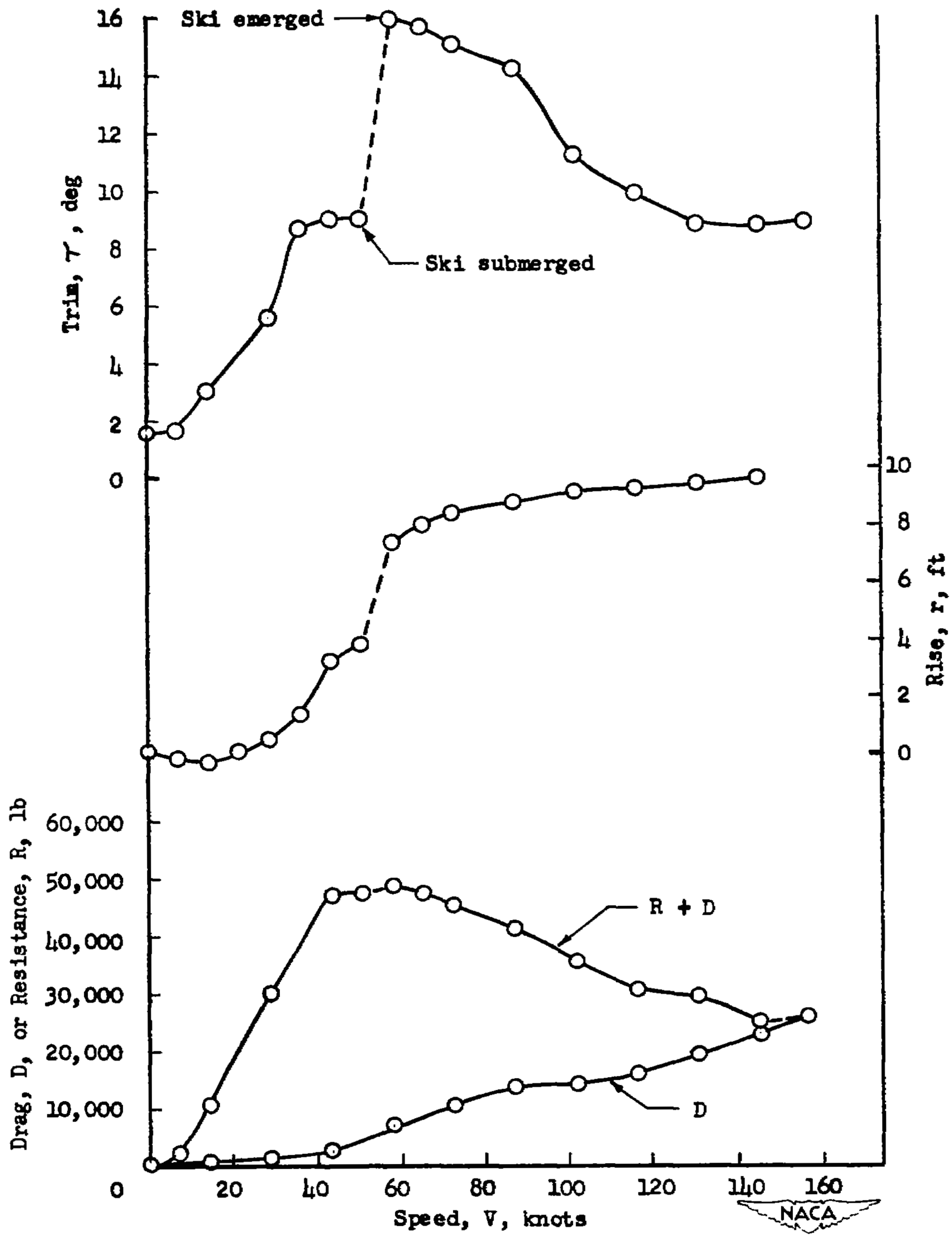

(b) Afterbody extension detached.

Figure 7.- Concluded.

V, 0.0 knots; τ, 1.3° V, 14.5 knots; τ, 2.7° V, 29.0 knots ; τ, 4.9° V, 43.5 knots; τ, 8.8°

V, 58.0 knots; τ, 7.6° V, 72.5 knots; τ, 14.5° V, 87.0 knots; τ, 13.8° V, 101.5 knots; τ, 11.8°

V, 116.0 knots; τ, 9.9° V, 130.5 knots; τ, 8.7° V, 145.0 knots; τ, 8.7° V, 159.5 knots; τ, 8.8°

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Figure 8.- Spray during take-off run with hydro-ski located at $0.45\bar{c}$ and $0.8b_s$ below the hull keel. Δ_o, 160,000 pounds; δ_f, 20°; δ_e, -20°; i_s, -1°; afterbody extension attached; all values are full scale.

[redacted]

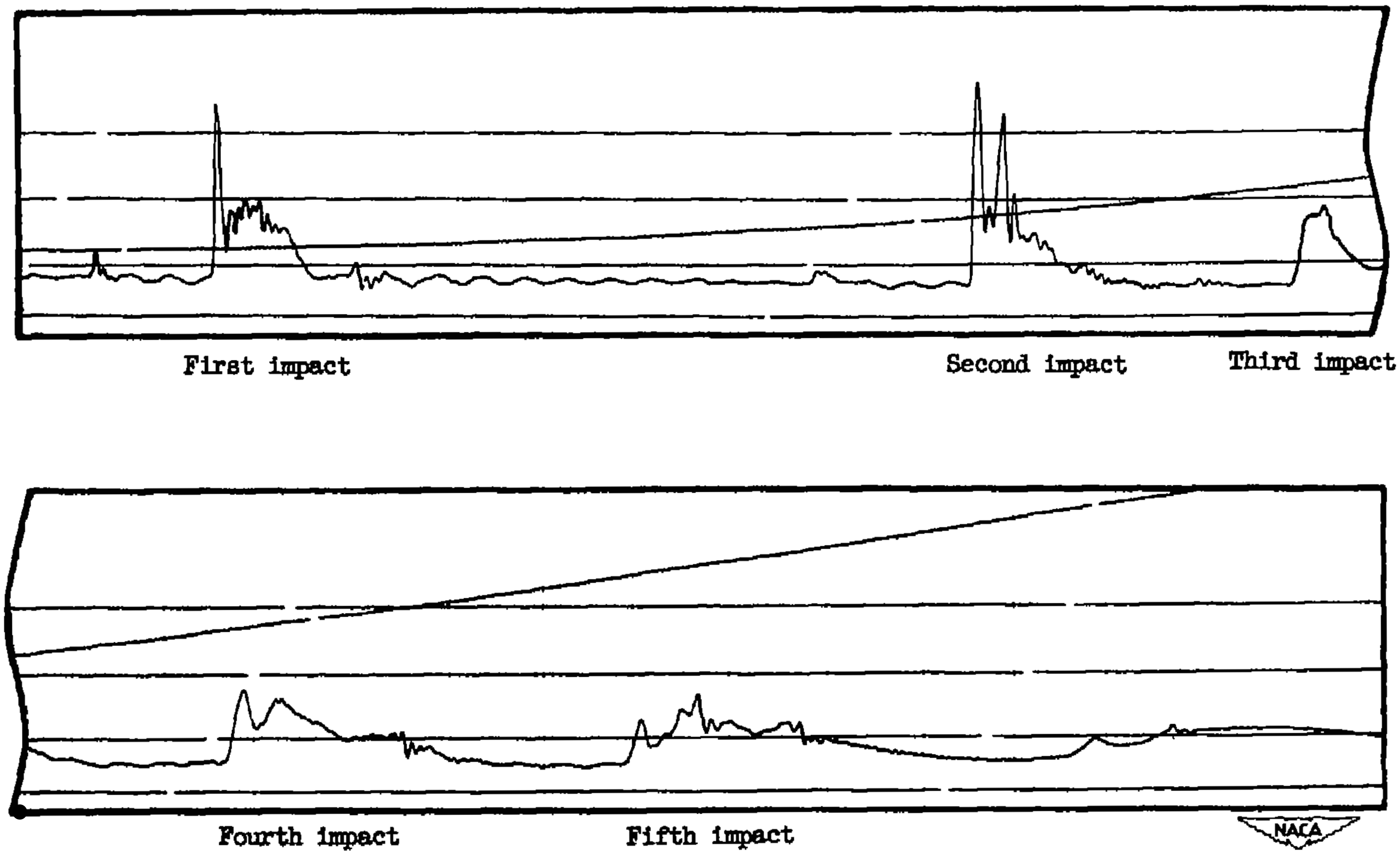
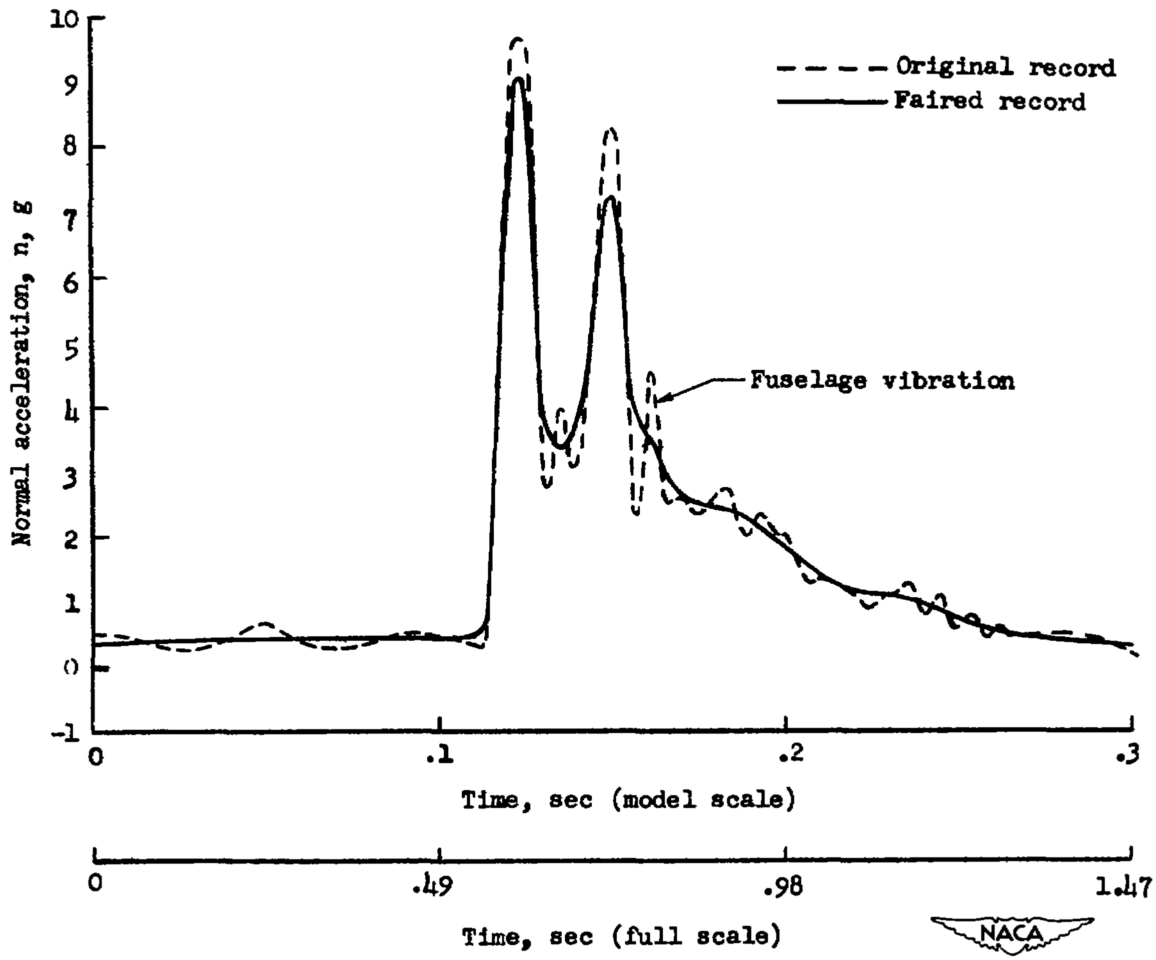
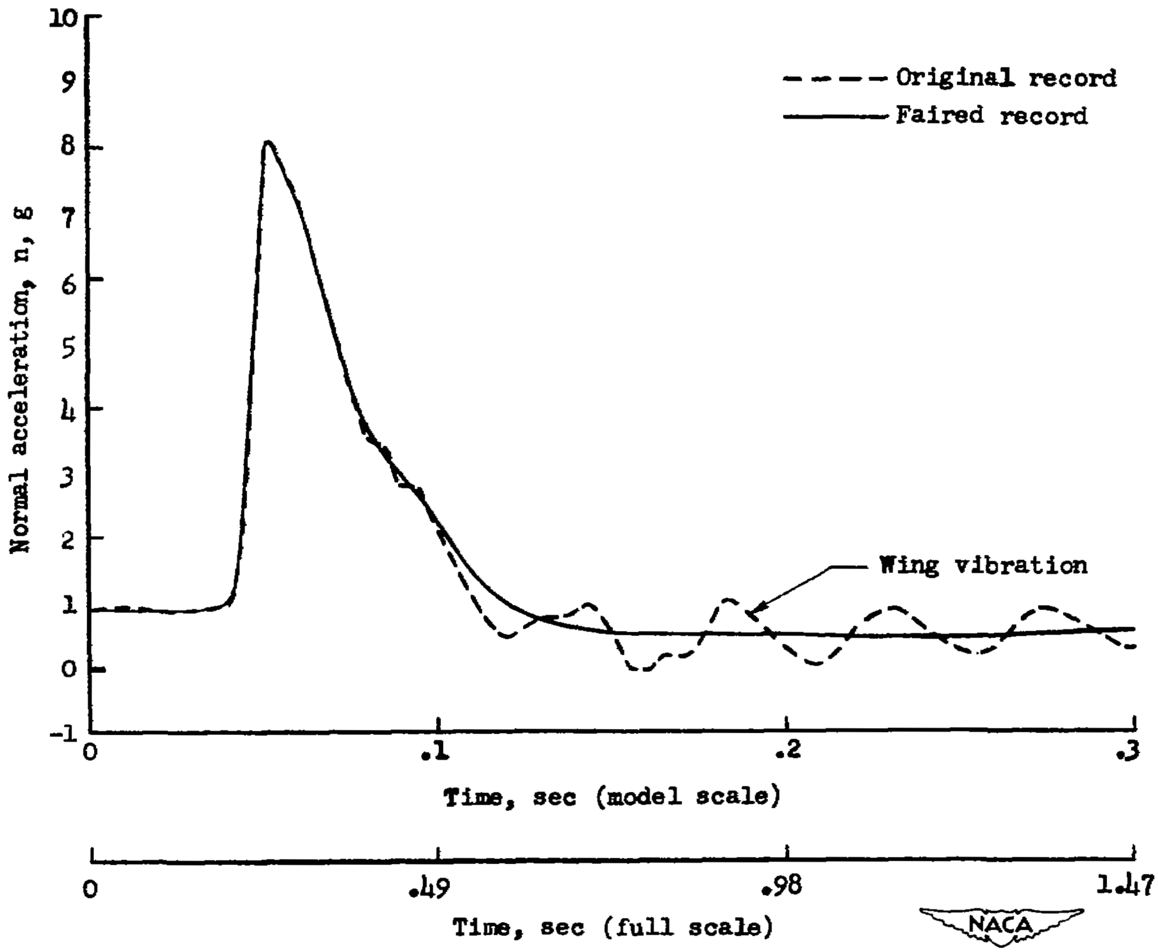


Figure 9.- Typical accelerometer record obtained from free-body landing in waves.



(a) Peak value reduced by fairing.

Figure 10.- Examples of accelerometer record fairing.



(b) Peak value not reduced by fairing.

Figure 10.- Concluded.

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SECURITY INFORMATION

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